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(54) Abstract Title
Electric coil with cooling means

(57) An electric coil, in particular a gradient coil for a magnetic resonance device, contains at least one electric conductor 12, a support structure 15a, at least one component 11a of a cooling device and a thermal insulating material 13a which is arranged between the conductor 12 and the support structure 15a for at least one section of the conductor 12. Preferably a coolant line is embedded within the conductor.

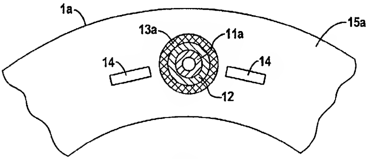

FIG 2

GB 2 364 784 A

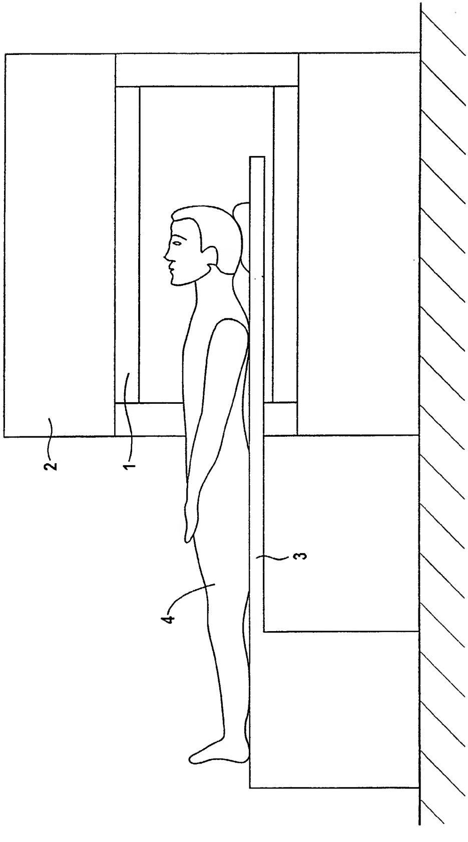

FIG 1

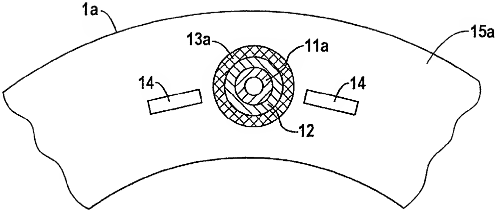

FIG 2

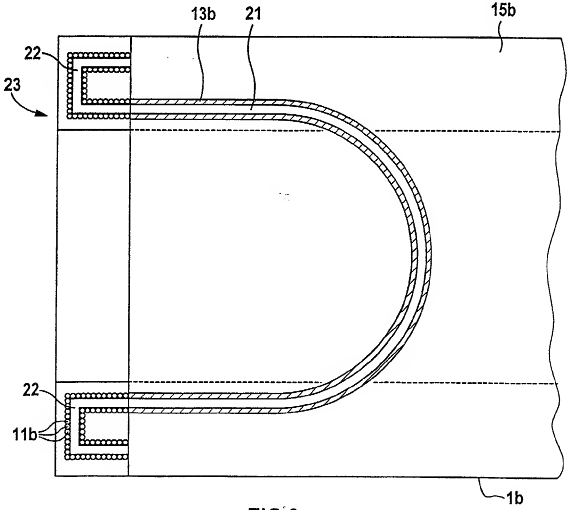

FIG 3

Electric coil

The invention relates to an electric coil, in particular a gradient coil for a magnetic resonance device.

The technical areas of use of electric coils are manifold. In many constructions an electric coil comprises, inter alia an encapsulation, for example of a synthetic resin in order to obtain a high insulating strength and a high structural strength. In addition, it is known to cool an electric coil, inter alia in order to increase its efficiency, during an operation of the coil. For this, for example, a cooling device transports heat, which arises due to a current flow in a conductor of the coil, out of the coil.

An example of a highly loaded electric coil is a gradient coil of a magnetic resonance device. The magnetic resonance device here includes inter alia a gradient coil system for generating rapidly switched gradient fields, together with a basic field magnetic system for generating a static basic magnetic field. The gradient coil system comprises in many cases means for reducing inhomogeneities in the static basic magnetic field; so-called shim devices. In the case of a passive shim device a number of iron plates are for example introduced into the gradient coil system in a suitable arrangement. For this the basic magnetic field is measured prior to the introduction of the iron plates and a computer program determines the suitable number and arrangement of the iron plates from the measured values.

During the operation of the gradient coil the amplitudes of the required currents in the conductor of

the coil come to several 100 A. The current increase and decrease rates come to several 100 kA/s. The driving voltage for the coil current comes to several kV. In order to control the above-mentioned high electrical outputs (or power), the gradient coil is frequently cooled. There is known for this, for example, from DE 197 21 985 A1 and/or DE 197 22 211 A1, a cooling device for the indirect cooling of conductors of the gradient coil. There is here introduced in a cylinder plane (or tier) casing of a hollow cylindrical, cast resin encapsulated gradient coil system a butt-laid flexible cooling line, through which a coolant is passed for the cooling of the gradient coil.

Another construction for the cooling of a gradient coil is described, for example, in DE 198 39 987 A1. Here a conductor of the gradient coil is cooled directly by a coolant being conveyed through an inner cooling duct which is surrounded by the conductor in a formation as a shaped segmental conductor.

From US 5 786 695 it is known, for example, that for a uniform accuracy of a shim effect a uniform temperature of a passive shim device is important. The heat generation in the conductor of the gradient coil leads to a change in temperature of the passive shim device, so that the homogeneity of the basic magnetic field and hence the quality of magnetic resonance images is affected. In order to prevent the above-mentioned temperature fluctuations of the passive shim device, it is proposed in the above-mentioned patent specification to arrange the shim device or shims in the gradient coil system in such a way that they are coolable by means of a cooling operation in order to obtain a high temperature stability.

It is desirable to create an improved coolable electric coil.

The invention is defined in the independent claim, to which reference should now be made. Further advantageous features are detailed in the dependent claims.

Thus, according to embodiments of the invention an electric coil, for example a gradient coil for a magnetic resonance device, comprises the following features:

- at least one electric conductor,
- a support structure (for the electric coil),
- at least one component of a cooling device and
- a thermal insulating material which is arranged between the conductor and the support structure for at least one section (or length) of the conductor.

The conductor of the coil is thereby operable at high temperatures, without the support structure, for example a resin encapsulation, simultaneously assuming dangerously high temperatures, which leads in advantageous manner to a reduced thermal expansion of the support structure and, particularly in the case of a magnetic resonance device, increases time stability of gradient fields and of the basic magnetic field. Since the conductor may assume high temperatures compared with the support structure, a coolant flow of the cooling device is operable with a high temperature drop, which permits high power densities within the coil.

In an advantageous development, at least one section

(or length) of the conductor is constructed in the shape of a hollow cylinder for the conveyance of a coolant. An embodiment of the above-mentioned conductor inner cooling is described for example in DE 198 39 987 A1 cited in the introduction. In particular, a construction of the conductor as a hollow circular cylindrical conductor produces in addition good high-frequency properties, for example in terms of the skin effect.

In an advantageous development the component of the cooling device is formed for the cooling of at least one section (or length) of the conductor. By virtue of the good heat conducting properties of the conductor, for example with a construction of the conductor from copper or aluminium, a formation of the component of the cooling device simply for one part or section of the conductor is sufficient to achieve a good cooling effect for a fairly big section of the conductor. Moreover, with the above-mentioned sectionally formed cooling, sections of the conductor which are not provided with the component of the cooling device may comprise said thermal insulation. Consequently, temperatures and temperature fluctuations occurring in thermally insulated conductor sections comparatively far removed from the site of the cooling, and which are greater than those at the cooling site, do not have a disadvantageous effect on the surrounding support structure. As a result of the above-mentioned, simply sectionally formed cooling, a correspondingly simple cooling device is constructable.

In addition, in an advantageous development the section of the conductor that is to be cooled (and the cooling component) is located to the edge of the coil, for example in an edge area of a spatial extension (or

extent) of the coil. For example with an extension in space forming a hollow cylinder, the section may be located in an area of at least one face (or front side) of the hollow cylinder. Due to an accordingly simple accessibility and short paths, the cooling device is constructable in a particularly simple and cost-effective manner. In addition, room is available in a central area for other components.

In an advantageous development the thermal insulating material surrounds the conductor. An all-round thermal insulation of the conductor is achieved in this way.

In an advantageous development the thermal insulating material exhibits a smaller thermal conductivity than the support structure, for example the thermal conductivity of the thermal insulating material is smaller than the thermal conductivity of the support structure by a factor greater than or equal to three. A support structure formed substantially from a resin encapsulation exhibits for example a thermal conductivity of about 0.15 W/(K · m) or more. Conversely, fibre- and/or rigid foam-type thermal insulating materials containing glass, ceramic, mineral and/or polymeric materials exhibit thermal conductivities of about 0.05 W/(K · m) and less.

In an advantageous development the support structure includes means for reducing inhomogeneities of a magnetic field, for example passive shim devices described in the introductory section. Accordingly there applies to the above-mentioned means what was disclosed in the foregoing with respect to the support structure. A complex separate cooling of said means in order to achieve a high temperature stability of said means is not necessary.

Further advantages, features and details of the invention follow from embodiments of the invention explained below with reference to the drawings, in which:

Figure 1 shows a diagram of a magnetic resonance device with a gradient coil system;

Figure 2 a partial longitudinal section through a first form of embodiment of the gradient coil system; and

Figure 3 a side view of a second form of embodiment of the gradient coil system.

Figure 1 shows a diagram of a magnetic resonance device with a hollow cylindrical gradient coil system 1, containing at least one gradient coil. The gradient coil system 1 is here formed to produce rapidly switchable magnetic gradient fields. The magnetic resonance device further includes a basic field magnetic system 2 for generating a basic magnetic field as homogeneously static as possible, together with a support device 3 on which for example a patient 4 is supported.

Figure 2 shows as an embodiment of the invention a section-wise longitudinal section through a first form of embodiment of a hollow cylindrical gradient coil system 1a. On grounds of clarity, there are here represented magnified, by way of example, a cross-section of an electric conductor 12 of a gradient coil and means 14 for reducing inhomogeneities of the static basic magnetic field. The electric conductor 12, for example of copper or aluminium, is formed in the shape of a hollow cylinder. Within the hollow cylindrical

conductor 12 is located, as a component of a cooling device, a cooling tube 11a, through which, for the purpose of a cooling of the conductor 12, a coolant, for example water, is conveyable. The cooling tube 11a is here formed of a non- or only slightly electrically conductive material, in particular of a flexible plastic.

Between the electric conductor 12 and a support structure 15a of the gradient coil system 1a, for example a casting resin encapsulation, is arranged a thermal insulating material 13a surrounding the conductor 12. The thermal insulating material is here of fibre- and/or rigid foam-type construction and includes glass, ceramic, mineral and/or polymeric materials, so that a thermal conductivity of the thermal insulating material 13a is for example smaller than the thermal conductivity of the support structure 15a by a factor of three. The conductor 12 may thereby assume comparatively high temperatures compared with the support structure 15a and a coolant flow is operable in order to obtain high power densities with a large temperature drop. A structure-damaging alternate heating and cooling of the support structure 15a surrounding the electric conductor 12 is thereby prevented. There is further achieved for the means 14 for reducing inhomogeneities of the basic magnetic field, for example a passive shim device in a construction as (conducting e.g. iron) plates, a high temperature stability and hence a high quality of magnetic resonance images. In one embodiment the electric conductor 12 and the cooling tube 11a are formed for example according to DE 198 39 987 cited in the introduction.

Figure 3 shows as a further embodiment of the invention

a side view of a second form of embodiment of a hollow cylindrical gradient coil system 1b. On grounds of clarity, there is here represented, by way of example for a cylinder jacket-shaped tier of the gradient coil system, simply one horseshoe-shaped conductor section 21 of a primary gradient coil. Said conductor section 21 is surrounded completely by a thermal insulating material 13b. On a face or front side of the hollow cylindrical gradient coil system 1b the horseshoe-shaped conductor section 21 is connected by connecting conductor 22 to a further conductor section (not shown), for example likewise constructed in a horseshoe shape, of an associated secondary coil. Conductors of the secondary coil are here likewise arranged in a cylinder jacket-shaped tier which surrounds concentrically the cylinder jacket-shaped tier of the primary gradient coil. The front-side connecting conductors 22 of the gradient coil are constructed so as to be coolable by their being surrounded in dense packing by cooling ducts 11b as components of a cooling device. A coolant is conveyable through the cooling ducts 11b.

The above-mentioned arrangement has in particular the advantage that components 11b of the cooling device are arranged only at an easily accessible face or front side 23 and the cooling device is accordingly constructable simply and cost-effectively. The inherently present high thermal conductivity of the horseshoe-shaped conductor section 21 is exploited here, whereby with an intensive cooling of the connecting conductors 22 an effective cooling of the horseshoe-shaped conductor section 21 is simultaneously achievable. The thermal insulating material 13b is here constructed according to Figure 2. The thermal insulating material ensures that temperatures and

temperature fluctuations occurring in particular in a section of the conductor section 21 which is comparatively far removed from the connecting conductor 22, and which are greater than those in the connecting conductors 22, do not have a disadvantageous effect on the surrounding support structure 15b.

List of reference symbols

1, 1a, 1b	gradient coil system
2	basic field magnetic system
3	support device
4	patient
11a, 11b	component of a cooling device
12	conductor
13a, 13b	thermal insulating material
14	means for reducing inhomogeneities of a magnetic field
15a, 15b	support structure
21	horseshoe-shaped conductor section
22	connecting conductor
23	face

Claims

1. An electric coil comprising the following features:

- at least one electric conductor,
- a support structure,
- at least one component of a cooling device and
- a thermal insulating material which is arranged between the conductor and the support structure for at least one section of the conductor.

2. An electric coil according to claim 1, wherein at least one section of the conductor is formed in a hollow cylindrical shape for the conveyance of a coolant.

3. An electric coil according to claim 1 or 2, wherein the component of the cooling device is formed for the cooling of at least one section of the conductor.

4. An electric coil according to claim 3, wherein the section of the conductor is located in an edge area of a spatial extension of the coil.

5. An electric coil according to claim 4, wherein with a spatial extension of the coil forming a hollow cylinder, the section of the conductor is located in an area of at least one face of the hollow cylinder.

6. An electric coil according to any of claims 1 to 5, wherein the thermal insulating material surrounds the conductor.

7. An electric coil according to any of claims 1 to 6, wherein the thermal insulating material exhibits a smaller thermal conductivity than the support structure.

8. An electric coil according to claim 7, wherein the thermal conductivity of the thermal insulating material is smaller than the thermal conductivity of the support structure by a factor greater than or equal to three.

9. An electric coil according to any of claims 1 to 8, wherein the support structure includes a resin encapsulation.

10. An electric coil according to any of claims 1 to 9, wherein the support structure includes means for reducing inhomogeneities of a magnetic field.

11. An electric coil according to any of claims 1 to 10, wherein the thermal insulating material is of fibre- and/or rigid foam-type construction and includes glass, ceramic, mineral and/or polymeric materials.

12. An electric coil according to any of the preceding claims, wherein the component of a cooling device is located to the edge of the coil.

13. A gradient coil for a magnetic resonance device according to any of the preceding claims.

14. An electric coil according to an embodiment substantially as herein described and/or with reference to the Figures.

Application No:	GB 0109669.2	**Examiner:**	Peter Emerson
Claims searched:	1-14	**Date of search:**	7 November 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H1P PHC, PSC; H1T TF, TTS; G1N NG38C, NG38

Int Cl (Ed.7): H01F 6/04, 6/06, 27/16; G01R 33/385

Other: Online: WPI, JAPIO, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	JP110262200 A	(TOSHIBA) - see abstract, figures.	1, 3-7, 12
X	JP110176630 A	(TOSHIBA) - see abstract, figures.	1, 3-8, 12
X	WO 95/12968 A2	(GEC) - p7 l 5-20, fig 1	1, 3-5, 7, 11, 12
X	WO 88/04057 A1	(FONAR) - fig 2	1, 3-8, 10, 12
X	US 5412363 A	(APPLIED) - fig 2	1, 3-7, 10, 12
X	US 4675636 A	(MITSUBISHI) - fig 3 and associated description.	1, 3-5, 7, 12
A	GB 2342986 A	(SIEMENS)	
A	US 4578962 A	(BROWN)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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